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ABSTRACT

This paper discusses whether or not educational research and practice have become too scientific and have consequently oversimplified the realities of teaching and learning. Arguments are given for focusing more attention on case studies and careful naturalistic observation in the design of educational practices. (MH)

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EDUCATION AS AN APPLIED SCIENCE

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My concerns in this paper are as practical as the designing, testing, and revising of courseware to cause the PLATO computer system to become a "teaching machine" for elementary school mathematics, or as the selection of effective strategies for teaching a high school mathematics course, or as playing a successful role as a parent. (Indeed, I have present responsibilities in all three areas that are exceedingly real and demanding!) That I am led, nonetheless, to some brief consideration of rather "scholastic" or "academic" matters is, I believe, inherent in the present state of affairs, because some of our biggest uncertainties are uncertainties about what sort of thing to look for and how to go about looking.

I. Some Fundamental Questions. Is there, in fact, a prospect of an "applied science" of education? I might begin by stating a few of my personal biases, to help the reader to discount them. I like the logical structure of mathematics, and if I could shape the world according to my wishes, I would give the study

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of education a logical structure similar to that which mathematics has. I also like the role of intuition, ingenuity, and insight in the heuristics of making mathematical discoveries, and I would like to see the study of education share this, also. Finally, though I have less direct personal experience with this, I greatly admire the success of physical scientists in creating abstract models that very precisely mirror physical reality in matters like force, velocity, acceleration, gravitational attraction, and classical electromagnetic theory. I would like to witness the creation of similar models for teaching, learning, and human information processing.

But I would NOT like to deceive myself into imagining these attributes for educational theory if this is contrary to fact. Precisely there is the rub.

What <u>are</u> the facts?

A. <u>What Is to Be Learned?</u> Looking at the knowledge which we want our students to acquire, do we know what <u>kind</u> of knowledge that is? Some of it, presumably, is information that is coded in commonly-shared symbols, such as natural English, or technical refinements of natural English, or the language of mathematics, the notations of organic chemistry, and so on. Let's call this <u>explicit, language-coded knowledge</u>.

It often seems that educational settings assume that <u>all</u> knowledge is of this type. One infers this from the prominence of books, lectures, and multiple-choice tests. There is, however, reason for doubt.

Saying "I must make the ball go straighter" does not necessarily make your muscles straighten out your hook in bowling. Saying "I want a more exciting first paragraph" doesn't automatically enable you to produce one. What does? On present evidence I'd have to say that I'm not sure. It may be some use of explicit language-coded knowledge, but then again it may not be. Most drivers develop a sense of when their car is following too closely behind the car ahead without needing to look at their speedometer, and a good mathematician can often quickly sketch out a proof of a theorem without working out - or knowing - the details. Is this achieved by some combination of explicit, language-coded knowledge, or not?

Recently, a student, concerned with generalizing

$$x + 3 = 3 + x,$$

said "That three doesn't have to be a three." [Davis, 1972]. I suspect this language, while literally meaningless, could easily be recoded into standard English - but this use of language shows some signs of slipping away from a precise, explicit use of standard English, into something a good deal more impressionistic - but very valuable, nonetheless.

The main point is that one does NOT, at present, know that all of the knowledge that we want students to acquire is (or can be) expressed in explicit "publicly-shared" common language. Since we do not know this, and even have some reason to doubt it, we probably cannot subscribe to a "science" of education that implicitly assumes that all knowledge is explicitly stateable in some "shared" language. This quite theoretical concern has, unfortunately, a great many practical implications.

[Incidentally, I interpret much of the recent study of heuristics by Papert and others, and much work in artificial intelligence, as investigations of how far we can invade this unknown territory of bowling, creative writing, mathematical thinking, chess playing, and so on, by using explicit language-coded knowledge. The verdict certainly isn't in, yet. Maybe explicit knowledge will take us the whole way, but we can't be sure at present.]

In any event, as one of my three examples will show, some of what we wish our students to acquire is of a different nature. We might speak of non-knowledge goals, such as the acquisition of good work habits.

B. Knowledge About Education. In the preceding section we were concerned with the things we want our students to learn. But how about our own knowledge of how to help students learn? That is to say, what can we know about teaching, learning, and the various aspects of human information processing and human performance? Everything that can be said about student knowledge applies also to our professional knowledge about education.

For one thing, we should notice that there are alternatives to what might be called "scientific" knowledge. The laws of harmony from the Haydn - Mozart - Beethoven - Brahms period are one instance. A scientific law is precise in its description both of cause and of effect. The common-practice-period harmonic rules were explicit and precise in terms of "inputs" or "causes" - what one should, or should not, do - e.g., don't use parallel fifths. But they were not explicit in describing the results that could be obtained, and the rules could

be broken - sometimes to excellent effect, as in the last movement of Beethoven's Opus 59 number 1. We cannot similarly choose to violate the law of gravity; moreover, given changing expectations of results, the laws of harmony can be replaced by a quite different set of admonitions, as in some contemporary electronic music; the results may be different, but may still be entirely satisfactory.

Consequently, the laws of harmony give us a concrete example of a useful body of knowledge that is not "scientific" knowledge.

Perhaps closely related to the laws of harmony are what Polanyi has called "practitioners' maxims." "Don't smile before Christmas" is one well-known example of a practitioner's maxim shared by some teachers. "Don't be afraid to show the child that you care about him" is another, shared by a rather different group of teachers.

Scientific generalizations are by no means the only kind of knowledge used by teachers, and are probably overshadowed, for most teachers, by some of the alternative forms of "knowledge." All of this adds up to the need for a more precise kind of analysis: we must go beyond words such as "science" or "art," and seek more precise descriptors such as "fully-algorithmic observation procedures," "detailed model-based conceptualizations," etc. When we conceptualize <u>heat</u> as the <u>motion of molecules</u>, we relate it to a model that deals also with kinetic energy, the pressure of gases, mean-free-path calculations, and so on. This is different, in an important way, from most statistical "knowledge." If we have statistical data on the effect of cigarette smoking

on the incidence of lung cancer, or the effect of vitamin C on the frequency and severity of colds, we remain unsatisfied. This does not go far enough to constitute an "answer." Why not? Apparently we feel a need to know, at a bio-molecular level, just how the vitamin C is involved in chemical reactions at cell walls, or what chemicals in cigarette smoke have what effect on DNA chemistry. Only at this level would we feel we had an "answer." This distinction gives rise to a descriptor like the one mentioned above: "detailed model-based conceptualization," and it is phrases such as this that are needed, rather than merely terms such as "scientific" or "objective."

The "scientific" study of education is further confronted with the possibility that many basic concepts have not yet been formulated correctly. "Force," "weight," "mass," and "acceleration" are instances of concepts that are <u>just right</u>, at least for classical physics. But if you study a classroom full of 9th graders who are learning algebra, or 13-year-olds practicing the piano, it is by no means clear that the usual descriptors and concepts of educational theory are sharply and correctly defined.

For all of these reasons, there is abundant justification for questioning how much of our professional understanding of "education" deserves to be called "scientific," or even should be cast in the mold of "scientific" thought, and in particular <u>there is great justification for fearing that a too-narrow definition of appropriate kinds of professional knowledge will prove harmful to the practical operation of educational ventures</u>.

Concerns of this type are now being voiced in many quarters. A random handful of books and journals from a few shelves in my office provided the following:

> One cannot help but question the significance of psychology's contribution to the development of effective instructional procedures. ...upon closer examination, it is evident that [various recent developments, including computer-assisted instruction] ...are not as closely linked to psychological research as many might believe.

> ...The more serious problem, however, is that psychologists know a great deal about the acquisition of individual facts and skills, but very little about how these combine to form a meaningful mental structure. Effective methods for acquiring skills and facts are important, but the major problem is the development of knowledge structures that are more than the sum of individual facts. In order to deal effectively with educational problems, we need theories that tell us how knowledge is represented in memory, how information is retrieved from that knowledge structure, how new information is added to the structure, and how the system can expand that knowledge structure by self-generative processes. [Atkinson, 1974]

The topic of educational research is one which is inherently controversial. Criticism has been based upon its amount as opposed

to the value of its results (Tate, 1950), the lack of productivity of its theories (Jacobson, 1971), its domination by psychology (Barron, 1972), and its lack of breadth (Taylor, 1973). To this list of complaints I would like to add another problem: the over-use and perhaps abuse of the linear model by educational researchers. It is my belief that the educational research community might do well to question the present use of the linear model and to consider an evaluation of its usefulness. The foundations of this problem go deeply into the sociology of knowledge where fundamental issues such as just how science progresses (or ought to progress) are debated. [Brown, 1975]

One reaction to disillusionment with the linear model could be a return to non-quantitative methods such as historical and legal analysis, the analysis of logical arguments, participant observation, interviews, non-numerical simulations, case studies and comparative approaches. Each of these is valid in its own context and is associated with a unique set of strengths and weaknesses. [Brown, op.cit.]

It is not difficult to appreciate why educational researchers are sometimes accused of a preoccupation with quantification (Mitra, 1974). Such criticism is especially justified when the

> linear model is applied when another form of analysis may be more suitable... . The major issue here is the basic assumption that understanding and control in the educational arena are to be acquired and augmented through the use of quantitative methodologies. If this premise is accepted, then it is an error to ignore the potential of more formal techniques using numerical methods. [Brown, op.cit., pp. 499-500]

But in fact, precisely this premise requires discussion. If, again, one looks closely at students and at schools, it is entirely easy to suspect that there are important kinds of knowledge that may not be of this nature.

> Rapoport and Horvath (1968) refer to Whitehead's notion of the hemming in of scientific thought and the threat of impending sterility because the culture "cannot burst through the framework of its own concepts..." They speak of the problem of assuming that a complex phenomenon can be understood by treating it (as the psychostatistical model does) as if it can be "broken up...into a temporal chain of events, all connected by determinate 'causal' relations." Such statistical studies of separate variables within the organizational process has, in our view, tested "ungrounded" and often meaningless hypotheses and promises sterility in organization and administrative education theory in the future. The time is long

overdue for another approach in education. The anthropological field study approach provides hope for breaking through this confining framework of present concepts and opening a new area for educational research. [Lutz and Ramsey, 1974]

While there are many possible criticisms of educational research, inconsistency of models is not one of them. It is natural to understand why certain disciplines which view the world in characteristic ways can afford methodologies which are relatively uniform and reflected in the research writings they produce. However, because the educational field must address a vast array of problems, it seems reasonable to argue that our theoretical and methodological tools used be correspondingly broad. Surely educational research should be more comparable to the diverse research in engineering rather than the more focused research in psychology. The danger of a highly uniform set of methods is sterility which precludes crucial problem solving due to the tightness of the imposition of the linear model paradigm. [Brown, 1975]

Most passionate, and far-ranging, was a commentary by Hazel Henderson, reported by Constance Holden:

In Henderson's view, corporations are not only central but are symbolic of what's wrong with the way we think about things. When

she speaks of the "Cartesian trip" she refers to the constellation of values and structures that have directed "progress" in this century - centralized, hierachical, huge organizational structures, the commitment to "big-bang, capital-intensive technology," the belief that science and technology are value-free, and over-emphasis on linear, objective, reductionist thought - or, dipping into psychology, what she regards as reliance on the brain's left-hemisphere thinking as opposed to the output of the right hemisphere, which is supposed to be the source of spontaneous, intuitive, emotional impulses.

She believes that recognition that all choices are based on values has fallen out of this rigid and highly compartmentalized system, and that the springing up of public interest groups is one of the signs that the system is beginning to crumble because of its increasing inefficiency in meeting peoples' needs and the growing social costs incurred. [Holden, 1975]

Very similar arguments, applied to the case of medicine, are presented in Carlson (1975).

The preceding quotes come from a quite literally random handful of books and journals. Had I deliberately sought them out, I could have found many, and more strongly worded, cautionary statements - for example in position papers written by Peter Hilton, Gerald Rising, Burt Kaufman, and others.

From all of this I conclude that we must move cautiously and wisely in the development of any theoretical understanding of education. There is a widespread and legitimate concern that obvious aspects may be treated in unsubtle ways, while the less obvious is neglected, with the result that elusive, complex, and profound qualities may become lost. We have seen this happen in recent years, and we have had chances to observe how a compulsive concern for secondary phenomena, when elevated to a level of policy, can be unmistakably harmful.

For the sake of the record, it should be mentioned that critics who object to "the linear model" do not all mean the same thing. Some refer to seeking linear relationships among variables; others object to the assumption that every valuable conceptualization is describable in terms of variables; still others object to the assumption that one first does research, after which one "applies" it, and point out that development often comes first, and is followed by research, as in the massive NASA development effort that put men on the moon, after which they picked up some rocks and brought them home for the purposes of research. This is most directly relevant to education. Personally, I would like to see some experimental schools started on the basis of developmental work, and carried to the point where they made possible some new ventures in research - perhaps including research into the hypotheses that underlie the original developmental work.

Let us turn now to some specific examples.

II. Motivation and Work Habits. In the fall of 1974, Jody Douglas, an anthropologist at the University of Illinois, lived briefly in the homes of 4 eighth grade students, observing adult/child interactions in the hope of getting deeper insight into why some students are motivated to do meticulous and virtually perfect work, and to learn lessons thoroughly, while other students are apparently content to think about academic matters in a superficial way, to pass in incomplete assignments (or even none at all), and to learn lessons imperfectly or worse.

On the basis of the Douglas observations, it was possible to identify two types of family environment, Type A and Type B. The Type A milieu is characterized by very frequent adult participation in decision making - Type A parents help select the clothes the child will wear to school, help decide which parties the child will attend, help decide how much TV, and which programs, the child will watch. In the contrasting Type B pattern, the child selects for himself the clothes he will wear to school each morning (and may even decide which clothes will be purchased), experiences little review (if any) of his social decisions, has relatively unrestricted access to TV (and may even have his own personal TV set in his room), and comes and goes with few if any restrictions. The expectations are as different as the actions: the child brought up in a Type A milieu clearly expects adult involvement in all of these decisions, and seems to accept this state of affairs. The Type B child does not expect adult "intrusion" into "his affairs," and resists any such intrusions. Even if adults are trying to help the child in fairly obvious ways, the child may refuse their help, so zealously does he defend his independence.

There is a difference, also, in what is done for the child. Type A parents spend more time supervising their children, but they also spend more time chauffeuring their children around, helping with homework assignments, etc. Type B parents allow the child to go many places, but mainly via bicycle, bus, or a ride with someone else's parents.

There are no major economic differences between Type A and Type B families - all were in the over $20,000 per year, and under $60,000 per year, income range, and lived in homes in the $40,000 to $90,000 range. All fathers were professional men. Type A mothers did not hold jobs outside of the home, since maintaining a Type A milieu was clearly a very demanding job; several Type B mothers did hold full-time jobs outside of the home.

There were no major I.Q. differences among the children; all had measured I.Q.'s over 125.

There was an absolute difference in ethnic background: all Type A families came from the same ethnic/religious background, and, while not identical, the ethnic/religious backgrounds of the Type B families covered only a narrow range, quite different from that of the Type A families.

Remember that the Type A and Type B milieu's were defined from observations of home environments. Their definition did not look at school performance.

But did the Type A vs. Type B distinction predict school performance? Yes, to a quite remarkable degree. Here is one instance: on the first mathematics test given the year following the Douglas study, there were 22 students

in the class that Douglas had studied. There was adequate data to allow the classification of 5 families as Type A, and 7 families as Type B; for the remaining 10 families, there was inadequate data to allow classification - but in any event, it is presumed that, with adequate data, the Type A and B categories would NOT exhaust the whole range of possibilities; presumably many other types of home environments would be identified if enough families were to be studied. Now, here are the examination scores on the first mathematics test of the following year:

Grades of students from Type A families:

97, 97, 93, 91, and 91.

Grades of students from Type B families:

73, 67, 66, 61, 60, 54, and 51.

Grades of students from unclassified home environments:

97, 91, 88, 86, 82, 80, 75, 60, 37, with one student absent from the exam.

This is by far the greatest predictive success that we have had. Does it tend to confirm or deny the notion that education has at last become an applied science?

I'm not sure.

Arguing for caution, arguing against a too-hasty acceptance of education

as an applied science, there are some points to be made: first, Douglas is an anthropologist, and it has been anthropological methods that have led us this far - anthropological methodology being about as remote from "laboratory" or "experimental" or "statistical" methods as one usually gets without leaving the realm of "science" entirely. Second, the patterns are classified as gestalts, not defined by thresholds on a single variable. This is certainly NOT the "linear model" that critics were questioning in the earlier quotations. Third, this work was based on direct naturalistic observation, and NOT on questionnaires or interviews or self-reports by subjects - methods that have thus far characterized a large proportion of the "scientific" study of education, much to its detriment.[2]

On the pro-science side of the argument, it is clear that next steps can be taken to pursue the Douglas study further, and that these next steps will include some recognizably "scientific" methodologies, in pursuing such questions as: will the distinction in student performance persist over time? Are there areas of study or performance that, unlike mathematics, will not show so large a correlation with the Type A/Type B distinction? Is it possible to identify a few key variables that reliably define the Type A and Type B

[2]Cf. also Kline-Graber and Graber's survey of research in human sexuality [Kline-Graber and Graber, 1975, pp. 23-27], where questionnaires are rated as the least reliable method of data collection, interviews next least reliable, observation by trained but relatively inexperienced observers next, with only direct observation by trained and experienced observers providing reasonably reliable data. Sex studies based on questionnaire and interview data have, in the past, painted a confused, contradictory, and quite inaccurate picture of human sex behavior. Only recently has direct observation finally begun to provide reliable data, from which a less contradictory picture is now emerging.

milieus? How well will this distinction hold up when larger numbers of families are considered?

But, again on the side of caution, one important class of further study deals with looking for actual detailed changes in student study habits that explain the differences in student performance - and this, as least at first, gets us back to direct informal naturalistic observation, a method often rejected by many advocates of a "scientific" approach.

Furthermore, we have come to suspect that much of the difference in performance can best be understood in terms of student self-concepts. students have a collection of descriptors of themselves, and of external events, and criteria for identifying and rejecting mismatches. A student who thinks of himself as conscientious would not be content to turn in an English paper that he considers "a shoddy piece of work." We also suspect that fairly deep introspection is required in order for a person to examine his own self-concept, and the future self that he expects to become. Added to our distrust of questionnaires, this gives us problems when we begin to plan ways to study self-concepts. This task resembles psycho-analytic investigations, and, once again, we find ourselves on the outside margins of "scientific" methods.

The goal, of course, is to solve as much of the problem as possible: to find out what patterns of achievement are associated with what patterns of childhood milieu. We must distinguish those methodological approaches that help us to solve the problem from those methodological approaches which impede our reaching a solution.

III. Designing and Evaluating PLATO Courseware. The University of Illinois has built, largely from inventions by Donald Bitzer, what is probably the largest CAI system in the world, known as the PLATO system.[3] From the point of view of a student using PLATO, he has before him, very roughly, a television set and an electric typewriter. (Actually, the "TV screen" is in fact Bitzer's plasma panel, with writing or drawing in an orange neon glow on a black background, and the keyboard is simpler than, and different from, a typewriter.) PLATO is capable of doing nearly anything that a lesson designer considers desirable.

For four years we have been engaged in programming courseware for PLATO, and during academic year 1975-6 there is underway an official evaluation of PLATO and its courseware, as presently used in elementary school reading and mathematics, in courses in computer science, accounting, algebra, and other subjects at the community college level, and in a wide range of university courses, including veterinary medicine, Latin, French, Russian, physics, biology, accounting, chemistry, computer science, and many others. I will speak only about the elementary school mathematics courseware, and I have two points that I want to make:

1. Concerning the evaluation, if one looks at what has been a matter of concern, and at what has not been, one is led to wonder how well we are being served by our present attempts to "be scientific."

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[3] For a description of the PLATO system, please refer to Nancy Wood. The PLATO System, Computer-Based Education Research Laboratory, University of Illinois, Urbana, Illinois (1975).

2. Concerning the creation of the courseware, what seems to be needed is skill in design - and design is, at the most generous estimate, only a small per cent "scientific," being mainly something else: luck, judgement, originality, creativity, experience, prejudice, preference, taste, convention, and who knows what else. Despite this fact, design is neither taught nor studied in usual educational circles. It is one of our most conspicuous omissions. Probably it must be approached via case studies, rather than via generalizations.

First, the evaluation. The elementary math courseware has been under construction for roughly three years, during which individual lessons have, of course, been tried out with children. We have called this special testing. It serves to help locate certain obscurities, ambiguities, and so on, but it provides next to no data about how the lesson will work when a student encounters it in its normal place in the curriculum. September, 1975, marked our first opportunity to have students progress through the entire curriculum according to the intended sequencing procedure, which combines computer control with occasional teacher judgements in determining the sequential order of lesson material. Thus this is, in a very real sense, our first-draft courseware; there has been no opportunity to try to match the lesson designer's guesses to the reality of children (except for "special testing," which does not address the most important questions), and to make appropriate adjustments. Whatever our attitude toward "science" as a

slogan, we do believe that the courseware MUST be tested against reality, and adjusted to improve the match.

Thus we have the spectacle of our first-draft guesswork going through the ritual of a "summative evaluation," as if it deserved to be considered a final product. There is an Alice-in-Wonderland quality about this entire proceeding that is easily understood if one regards this as an instance of essentially political behavior, but it cannot be reconciled with a seriously "scientific" approach.

Far from claiming that our first-draft courseware is a finished "package" ready for final evaluation, we would prefer guarantees that our first-draft efforts will NOT be released to the world at large until after extensive revisions and modifications have been made.[4]

But there are even deeper reasons for questioning whether the evaluation supports the notion of a "scientific" approach, or rather brings it seriously into question. Before going on I want to emphasize that my remarks are not

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[4] One important piece of reality concerning the creation of PLATO courseware is that a very large amount of DEVELOPMENT has to be done BEFORE one can do the important RESEARCH - you have to have at least a minimally viable system of courseware, in operation in at least a dozen or so classrooms, before you can observe the effects on teachers and children. The out-of-context "special testing" cannot shed much light on what will happen during day-to-day routine usage. Few things could be less scientific than to assume that a child's 10-minute interaction with an out-of-sequence PLATO lesson need only be multiplied by 600 to predict the result of routine day-in-and-day-out use 30 minutes per day, 5 days per week, 40 weeks per year, in its intended sequential order, where carefully building and developing mathematical ideas is one of the major goals. This represents one more failure of the "linear" model, which assumes that research comes first, and is followed by development.

criticisms of the evaluators. The evaluation has attracted considerable attention, since the over-all effort is a ten-million-dollar venture, at a time when resources are not generously available, with the result that the evaluation has become caught up in those complex political processes where no man can be said to be in control. Probably everyone involved with the evaluation would want it done differently if they could impose their will on the venture - although people do not agree on how it should be changed. Thus doubts about the evaluation are doubts about the practice of evaluation in 1975, with the problem of resource allocation and political processes very much a part of the picture.

For one thing, what proposition is being tested? For some people, the proposition says something like this: if, to your regular school curriculum, you add daily work on PLATO, using whatever courseware may be available, student performance in mathematics, measured by any conveniently available tests, will show an improvement.

I cannot take that proposition seriously. It seems just barely removed from an absolutely magical faith in PLATO as an infallible teaching machine. Worse, it envisions a use of PLATO which, I feel, should not be allowed to occur. I cannot believe that effective educational programs are so chaotically random. Surely, it must matter that learning experiences be somewhat matched to learner characteristics, and this proposition ignores the whole question of whether students are getting appropriately-selected learning experiences.

We have a different proposition in mind:

We believe that, if one starts (as we have) with a diverse collection of courseware, showing some measure of over-all organization, yet including several competing approaches; if one puts this courseware into use in a dozen classrooms; if lesson designers and classroom teachers work together to find which classroom roles PLATO can play most effectively, and how teachers can best use PLATO and PLATO courseware; if, on the basis of this experience, you make adjustments (and even major revisions) in the courseware; if, as you find how teachers can best use PLATO, you develop a teacher-training program; and if you develop, test, and revise appropriate off-terminal materials, then you should get to a point where new teachers, initially selected for general competence, who then go through your teacher education program successfully, and who then use PLATO (together with the off-terminal materials) in their classrooms in general accord with the scheme you have worked out, should find that most of their students are learning more mathematics (in a sense which we would make reasonably precise) than had formerly been the case.

That is a proposition I can, and do, believe in. It is NOT, however, the proposition that is actually being tested. Indeed, many critics of the evaluation reject this proposal as "unscientific," arguing that PLATO must stand alone, without benefit of a teacher-training program. But if "science" requires that PLATO stand alone, without being integrated into an over-all classroom program, then "science" is requiring that we engage

in poor educational practice, and that is far too high a price to pay.

Indeed, we see here one of the major fears of those who resist "being more scientific": the fear that, in order to have a universe that can be studied more cleanly, we shall put educational practice on a Procrustean bed, and chop off anything that doesn't fit our simple conceptualization. We thus get a "reality" that is easier to study, but one that cannot be optimized in any effective way.

In fact, the elementary math courseware is organized into three separate "strands," and each strand has been produced by a different team, designed according to three different sets of assumptions.

The so-called "graphs" strand (dealing with variables, functions, graphs, negative numbers, etc.), while the least conventional in content, is the most conventional in presentation. Straightforward mathematical tasks follow the "discovery" format used in earlier trials of this same material in face-to-face teaching. The sequencing follows a "spiral curriculum" pattern, which means that an idea is not completely developed in a short time interval; rather, the student cycles back to it, in different forms, so that the idea builds up gradually: intuitively, at first, followed by gradual explication and further development. Actual experiences are straightforward explorations of mathematical situations.

The "fractions" strand uses a "story" format: for example, in operating a pizza stand and filling orders for one-third of a pizza, etc. The sequencing

is fairly linear, with an idea being developed in a relatively short period of time; the pre and post testing is the most fully developed of any strand, and certain levels of success must be achieved before a student is allowed to go on to new material.

The "whole numbers" strand is the hardest to describe. The curriculum sequencing is very loose, and most experiences are in the form of games, so that one gets the impression of a collection of games that may be played in any order whatsoever.

This diversity of approaches creates a real possibility for evolution. As classroom experience develops, and revisions are made, the different strands will inevitably come to resemble one another more closely, but the initial variety means that the evolution may proceed in whatever direction classroom experience shows to be most desirable - it is evolution in an almost biological sense, where variation and selection for superiority are the two cornerstones. By contrast, if all of the courseware were organized according to a single format and a single educational philosophy, we would be largely locked into that single approach. Extensive evolutionary modification would be quite unlikely.

I propose to estimate the vigor and appropriateness of today's "scientific" approach to evaluation by reviewing some of the things that <u>have</u> been matters of concern in the PLATO evaluation, and some of the things that have <u>not</u> been.

<u>Things that have NOT been matters of concern (but should have been)</u>.

We have already mentioned the lack of concern for the fact that only a preliminary version, a "first-draft," of the courseware is being evaluated as if it were a final product.

We have also mentioned the lack of concern for which propositions about PLATO are being tested. The conventional wisdom deals so exclusively with "complete packages" that PLATO, and its attendant courseware, are automatically construed to constitute a complete package. Teacher training, in this view, would be an inappropriate contamination of a "scientific" evaluation.

Also neglected is the fact that PLATO uses a single, very large, time-shared computer, and that 800 terminals are located all over town, in schools, university classrooms, libraries, offices, and even homes. Every terminal is connected to the same computer. PLATO is very popular with students. Thus, when it is assumed that a class is a "control" class because there are no terminals in that classroom, this assumption is less than safe. Many children in "control" classes are, in fact, regular users of PLATO, on evenings and weekends, either at a university site, or at their father's office, or even at home. A good journalist would have found this out rather quickly; the "scientific" approach to evaluation did not raise any questions in this area. A control is a control is a control.

Which child is signed on? PLATO, of course, can't tell. When from generosity, extortion, or otherwise, one child acquires another child's "secret password," the door is opened to considerable doubt as to which child is actually signed on. This has not been seen as a matter requiring study.

Who is in the experimental group? Given what has been said above, there follows another problem. If some "control" children are actually on PLATO, it is equally true that some children in the "PLATO" or "experimental" classes do not use PLATO. They trade their turns to other children.

In two instances, a teacher who teaches two classes is serving as his own control: PLATO is used in one class, but not in the other. Of course, to the extent that PLATO achieves its results indirectly, by influencing teacher behavior, these "control" classes may actually be PLATO experimental classes.

We regard the teacher's role as crucial. Yet this is not receiving very careful study.

In some cases, special-extra help, from university volunteers, is being provided to non-PLATO students, because teachers perceive these children as being denied the advantages of PLATO sessions. This, again, raises questions as to what proposition is being studied. Is it the relative advantage of human help over machine help?

The tests used in the evaluation include some widely-used standardized tests of mathematical achievement. Some of these tests do not include, among the possible answers, the most likely "wrong" answers. E.g., on one question, $6 \div \frac{1}{2}$ does not include "3" as one of the possible answers.

The reading level of the students was not a matter of concern, even though the auto-tutorial aspect of PLATO relies entirely upon reading and writing

for computer/child communications.

But most important of all are these two omissions: the trial is not seen as a brief time slice in an on-going evolutionary process, where continuous observation leads to continuous modification and adjustment of the program, and very little attention is focussed on the most important question of all: what actually happens when a child sits at a PLATO terminal and attempts to work through a mathematics lesson.

This sort of thing does not seem to fit easily into present-day "scientific" conceptualizations of CAI evaluations.

A fundamental point of disagreement is over the nature of feedback data that should be used for program modification. We believe in watching the children very closely, and making courseware changes quickly when they seem to be needed. Two minutes of observation of one child may give enough data to suggest a revision, and a further hour or two of observing a few other children may confirm this to the point where we believe the change should be implemented - that same day! We are very eager to gather long-term data, but we do not think one should spend a year collecting data in order to decide what changes to make. Such a time scale is completely wrong.

Of course, every "omission" listed above could be embraced within a scientific study of PLATO - but that is not the question. Rather, we ask: how real is the danger that the slogan of "being scientific" will be used to justify the process of over-simplifying reality, constraining it to find

a rudimentary conceptualization, and ignoring everything that doesn't quite seem to fit. From our present vantage point, the danger seems very real indeed.

Things that WERE of concern in the evaluation.

Obviously, and correctly, socio-economic status of students was a matter of concern, in the sense that control and experimental classes needed to be matched for S.E.S. But one moves from this important truth to a rather dubious proposition: it was felt that a wide range of S.E.S. children should be represented in the test population. Why? The modification of courseware to appeal to different student populations should be a separate task. There is something magical in assuming that specific attention to demographic modifications is unnecessary; a broad-range success should just automatically appear, coming from nowhere.

It has been strongly suggested that the teachers who use PLATO should have been selected randomly, instead of taking volunteers (which is what we did). There seem to us to be two major errors in this: we would never tell a teacher that he or she had to use PLATO, whether they wanted to or not - that seems to us to be the wrong way to run schools; also, there is again the question of what proposition is being tested - we do NOT believe that randomly-chosen teachers should be using PLATO, perhaps even against their wishes. The only question that makes educational sense to us sees PLATO as part of a larger program, including off-terminal materials and special teacher training, being used by teachers who want to use it, and who enter

the program already competent in traditional teaching skills.

Once again, a concern for the slogan of "being scientific" seems to distort the educational reality in quite harmful ways.

There was concern to eliminate the so-called "geographical variable." This resulted in trying to match experimental and control classes in the same school - ignoring the fact that the teacher pairs that resulted consisted of extremely different teachers, who were not comparable at all (differing in sex, race, teaching styles, personalities, and educational philosophies), and ignoring the fact that contamination of the control class by children getting into PLATO when they weren't supposed to was widespread since the classrooms were side by side.

This pattern of decision-making based on slogans of "being scientific" seems to us ritualistic, a kind of magical thinking, an assumption that looking carefully at the schools, the teachers, and the children is unnecessary, that instead one should manipulate certain symbols (like the "geographical variable") sanctified by the professional literature, and assume that one has thereby dealt effectively with the reality. To the extent that the slogan of "being scientific" is used in this way, it seems seriously detrimental to the improvement of education.

Let us turn now to the task of designing PLATO lessons.

One attribute of our design work is that it is theory-related. For theoretical reasons we distinguish (at present) seven curriculum tasks, as follows:

readiness-building

paradigm creation (cf. Davis, 1972)

practice of routine skills ("sskills," in the sense of Henkin, 1975)

developing algorithms or procedures ("sub-routines" or "programs" in the sense of computer programming or artificial intelligence)

developing higher-level procedures that select, sequence, or modify sub-procedures (cf. Davis, 1975)

practice in non-routine settings (which includes, as a sub-category, experience in pattern discovery)

developing explicit heuristics

Another attribute of our lesson-design is our use of minute naturalistic observation of what happens when a child sits at a PLATO terminal and tries to work through our lessons.

In point of fact we do try to be "scientific," in that we seek careful explication of whatever we do intuitively, to the fullest extent that we can achieve such explication; we seek generalizations or propositions that may be testable; and we try for objective observation procedures. Unfortunately, reality continually confounds this effort. The situation-specific attributes of lessons continue to dominate the generalizable aspects. Let me give a few

examples, taken from actual observation notes. Please notice that these examples cover a lot of ground, ranging in a sense from the sublime to the ridiculous, and demanding cures ranging from trivial correction of obvious design errors, to quite subtle and profound modifications, sometimes even requiring the creation of a greater artificial intelligence capability with PLATO's programming:

Example 1. A lesson on open sentences, like

$3 \times \square = 12$

$\square + \square = 8$

etc. (from the Graphs Strand).

Problem 1. Students choose equations to work on from a list of 37. The vast majority of these require non-integer solutions. At present the curriculum makes no check to see that students know something about fractions or decimals, and many of them don't.[5] Students are usually not ready for this lesson - at least in its present form. I have watched many students in this lesson, but I have yet to see one for whom this lesson was a useful learning experience (with one possible exception, whom I discuss below).

Problem 1 could be solved in many ways: the curriculum checks could be inserted; the problems could be classified into appropriate categories, and students could get the easier categories first; the categories could be labelled,

[5]Recall that the present year of classroom trials is the first testing of all of the courseware, with full use of computerized lesson selection.

so a student would know what to expect; one or more sample problems could be worked out on PLATO as illustrations; HELP sequences could be designed; or an off-PLATO introduction by the teacher could be provided, using hard-copy materials that we could create. Probably several of these improvement should be made.[6]

Problem 2. The "one possible exception," mentioned above, was a very bright and conscientious girl named P., who got to

$$10 \times \square = 101$$

and, unlike the other children, did not give up. However, P. did not know what to do. She had tried 11 and found it too large, and 10 and found it too small. P. had not yet gotten to fractions, neither in the second curriculum nor on PLATO. She had some very vague ideas about how decimals might work. She finally decided to try - tentatively - 10.1. She keyed in 1, then 0, then the decimal point. The lesson accepted the 1 and the 0, but rejected the decimal point. She accidentally pushed NEXT, not meaning to, and the lesson cycled her through a long routine to show that 10 was too small, which she already knew; there was no way to jump ahead in this sequence.[7] Because she couldn't key it in, she couldn't try 10.1 to see if it would work. At this point she needed,

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[6]Part of the difficulty here is that the lesson designers wanted this lesson to serve as "practice in a non-routine setting." Some of the proposed remedies would remove the lesson from this category.

[7]In an earlier version of PLATO, called PLATO III, the keyset included a key labelled "AHA!"; this terminated a HELP sequence, signifying that the student now saw the difficulty and wanted to proceed on his own. This key may need to be reinstated.

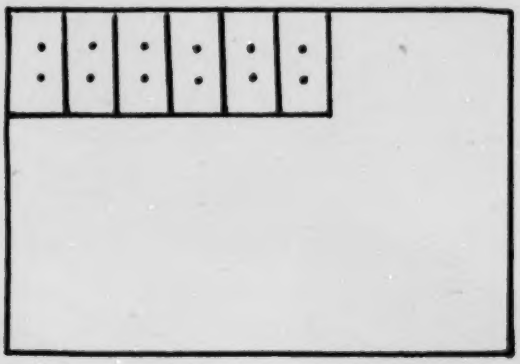
and got, some human help, from an adult who asked (as PLATO could have done) "How many tenths in one?" She answered "10". Adult: "How many tenths in 10?" That took more thought, but P. finally decided there were 100. At this point she wanted to try $\frac{101}{10}$. Neither she nor the adult had really noticed a line on the screen that said "If you want to put in a fraction, press f." [In many lessons we have so much writing the kids are learning not to bother reading most of it.] Finally somebody noticed this line, so P. pushed f and a small arrow appeared in a raised position, apparently ready to accept a numerator. P. tried to key in 101, but the lesson accepted only 10, apparently not accepting three-digit numerators. At this point P. could think of no way to try out 10.1. She had to appeal to an adult, who showed her how to key in a correct answer (as a mixed number).

The solution here is trivially obvious, but does need to be made, and making the necessary changes can dramatically alter the impact of this lesson on children.

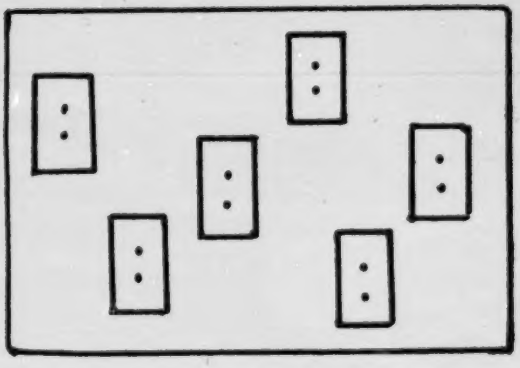
Example 2. In order to help children know what mathematics to use in "word problems," there is a sequence dealing with the "meanings" of the various operations (in the Whole Numbers Strand). The lesson in question is intended to establish two meanings for multiplication: the "repeated addition" meaning ($7 + 7 + 7 = 3 \times 7$, etc.), and the "replication" meaning. The student is given a "rubber stamp" and a rectangle representing "a piece of paper." Each time he stamps on the paper, he marks two dots.

The lesson <u>assumed</u> that a child would stamp in an essentially meaningless

pattern, such as either



or



after which the student was expected to write a description of the dots in an addition story

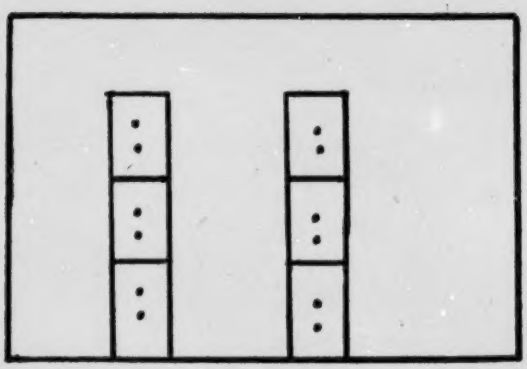
$$2 + 2 + 2 + 2 + 2 + 2 = 12$$

and then in a multiplication story,

$$6 \times 2 = 12 \quad .$$

One child I watched this week - a minority boy who seemed rather defeated by school in general, and always on the verge of giving up, - in any school-related situation - had made a rather careful pattern that I imagine he was

rather proud of:



He tried to describe his creation by the addition sentence

$$6 + 6 = 12 \ ,$$

but the lesson rejected this. He couldn't understand what was wrong. An adult finally intervened and told him that the lesson probably expected the answer

$$2 + 2 + 2 + 2 + 2 + 2 = 12 \ ,$$

so he typed this in, and it was accepted. Then the lesson asked him to describe the dot situation by means of a multiplication statement, and he was completely stumped. After he had sat there for some time, an adult asked him [following George Polya's advice about the "inventor's paradox" heuristic] how much 7 2's would add up to. The boy answered correctly, but again could not make a multiplication sentence; the adult asked how much 15 2's would add up to. The boy answered correctly, and was now able to make the relevant multiplication sentences in each case. [David Page suggested the strategy of moving to larger numbers in order to clarify the algebraic structure of a situation.]

Without adult intervention, this lesson failed, but it could easily be fixed up.

Solutions: 1) The lesson could be more accepting of student responses. Given the student response

$$6 + 6 = 12 \ ,$$

the lesson could ask: "Does your arrangement of stamps suggest 6 + 6?" (or some such thing), thereafter saying: Alright. Now suppose we ignore how the stamps were placed, but try to count the dots just from the fact that there are 2 dots on each stamp. Would this be a good description:

$$2 + 2 + 2 + 2 + 2 + 2 + 2 = 14?$$

[This would lead to answer "No, because, there are 6 stamp marks on the paper, and the addition sentence uses 7 2's", which might be developed via some multiple choice questions - the point here is to get students answering, without making them guess what was in the mind of the lesson designer.] The lesson would then go on to establish

$$2 + 2 + 2 + 2 + 2 + 2 = 12, \text{ etc.}$$

2) Or one could use a somewhat simplified version of solution 1, making more use of PLATO responses like: "Well, 6 + 6 = 12 is true, but what I had in mind was

$$2 + 2 + 2 + 2 + 2 + 2 = 12."$$

3) Or one could change the lesson by having PLATO work the first example, by way of illustration. This is probably a major difference cognitively, for the cognitive task now is merely one of copying an example, which does NOT necessarily require the same kind of thoughtful analysis that 1 or 2 would. Solution 3 is probably cognitively inferior to 1 or 2, but would be better than just leaving the kids stuck, as the present version does.

Example 3: Another boy - again, a defeated-appearing minority child who doesn't seem to hold high hopes for school - working in the lesson where you move a turtle to his food, in order to learn to plot points in the first quadrant in Cartesian coordinates.

This boy hardly reads any writing on the screen, and may have a very low reading level. He strikes keys so rapidly - and sometimes almost randomly - that the lesson can't keep up with him. It is continually trying to flash a message from 8 or 10 key-presses back.

It seemed to both observers that the boy was not building up any patterns of mathematical structures in his head. On the contrary, he was approaching the lesson in the spirit of those psychological experiments where you hit some pattern of buttons to make certain lights go out. At his fastest and most frantic rate, I doubt that he knew the labels on most of the keys he hit. He finally worked out the following pattern: if (say), a message appeared on the screen saying:

"The food is at (3, 4)",

he would press 3 [which actually had no effect but he didn't realize that], then press 4 [again, no effect], then push the key until the turtle stopped moving, then push the key until the turtle stopped moving, then push NEXT. [Even this much order was achieved only after an adult got the boy to stop his wild hitting of the keys.]

I cannot say that this boy was learning mathematics. It is entirely possible that he had never even noticed the graph, axes, coordinates, etc.

Solution: I think the best solution for this type of child is intervention by a helpful and supportive adult, though obviously there are some improvements that could also be made in this lesson. [Notice the underlying problem here.]

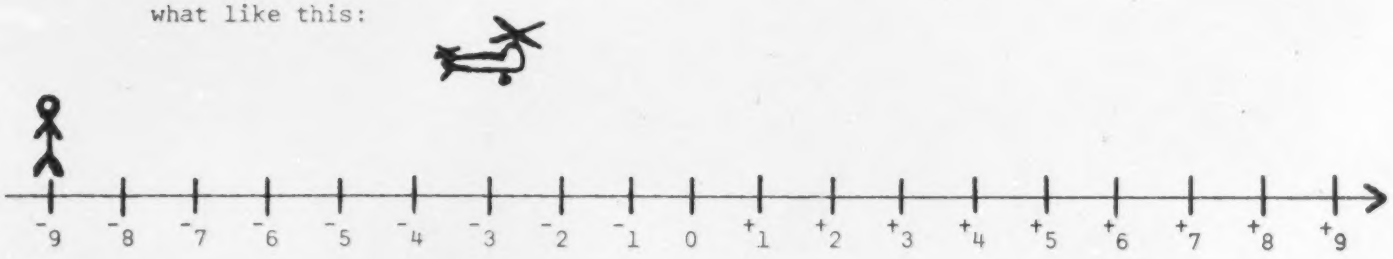
If a student is allowed to make an unbounded sequence of errors (which no teacher would allow in face-to-face teaching), the student can become hopelessly mired down in confusion, making no progress. [In such a case, the computer reports this situation to the teacher, but one obviously prefers to have PLATO solve its own problems wherever possible, since demands on the teacher's attention are always too numerous in any classroom.] But, on the other hand, if N errors (for some value of N) activate some automatic help sequence, then students need not analyze problems at all - they can merely hit keys randomly until the help sequence appears.

Good lesson design obviously has to try to operate between these two extremes. The reader can probably easily invent modifications that will eliminate the difficulty in the present instance.

One could even make a system for doing so - but we feel that systems should NOT be so evident to the learner that sessions on PLATO become entirely routine. [Variety is the spice of CAI.]

Example 4. A girl, Cecily, working on the "egg-dropper" lesson. This lesson is essentially a readiness building experience for the addition and subtraction of signed numbers. A "victim" - a man standing on a number line - is shown at, say $^{-}9$ ("negative 9"). Higher on the screen, a helicopter hovers

directly over $^{-}3$. The student (who has voluntarily selected this form of the lesson, presumably because he enjoys pretending to drop eggs on people's heads), by keying in $^{-}6$, would move the helicopter 6 units in the negative direction, thereupon dropping an egg (and scoring a direct hit). The screen looks somewhat like this:



Instead of keying in $^{-}6$, Cecily keyed in $^{-}5$. [The observer's notes record that this was the second time Cecily had missed by one unit.]

Using random numbers, the lesson then offered the following sequence of problems:

1.	victim at	$^{-}7$	
	helicopter at	$^{-}6$	
	correct answer	$^{-}1$	
	Cecily's answer	0	
			missed by 1 point
2.	victim at	$^{-}10$	
	helicopter at	$^{-}13$	
	correct answer	3	
	Cecily's answer	3	
			direct hit!
3.	victim at	$^{-}13$	
	helicopter at	$^{-}8$	
	correct answer	$^{-}5$	
	Cecily's answer	$^{-}5$	
			direct hit!

4.	victim at	4	
	helicopter at	-4	
	correct answer	8	
	Cecily's answer	5	
			missed!
5.	victim at	-13	
	helicopter at	-10	
	correct answer	-3	
	Cecily's answer	-3	
			direct hit!
6.	victim at	-11	
	helicopter at	-11	
	correct answer	0	
	Cecily's answer	-0	[sic]
			direct hit!
7.	victim at	-12	
	helicopter at	-6	
	correct answer	-6	
	Cecily's answer	-5	
			missed by one unit!
8.	victim at	-7	
	helicopter at	1	
	correct answer	-8	
	Cecily's answer	-5	
			missed!
9.	victim at	-2	
	helicopter at	-7	
	correct answer	+5	
	Cecily's answer	+6	
			missed by one unit!

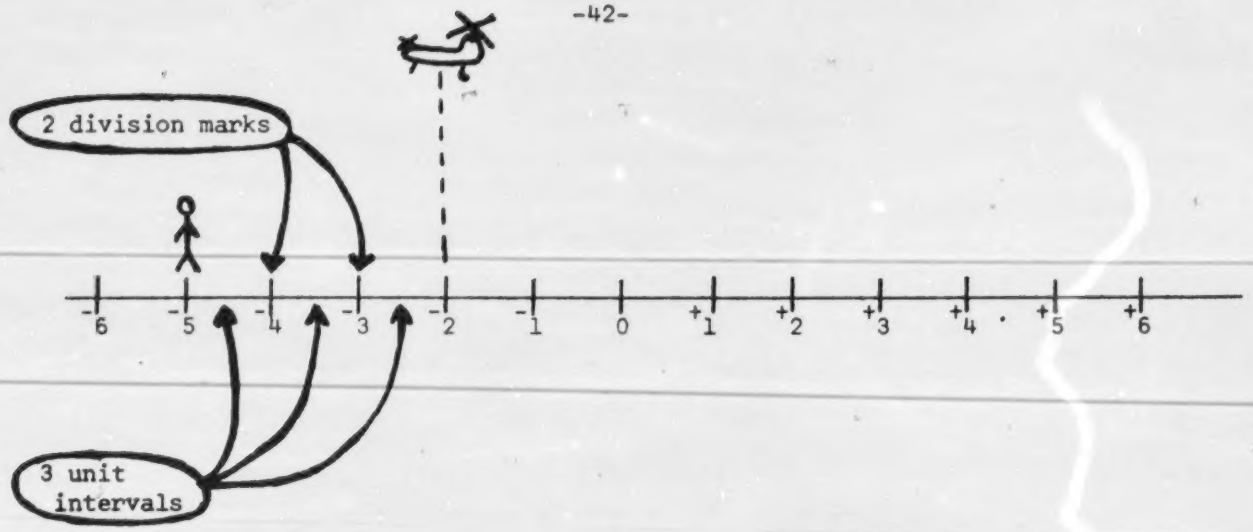
10.	victim at	$^{-}11$	
	helicopter at	$^{-}3$	
	correct answer	$^{-}8$	
	Cecily's answer	$^{-}6$	
			Missed, and, for the first time Cecily spoke aloud; in fact, she screamed: "Oh! It's minus seven!"
11.	victim at	$^{-}4$	
	helicopter at	$^{-}6$	
	correct answer	$^{+}2$	
	Cecily's answer	$^{+}2$	
			direct hit!
12.	victim at	0	
	helicopter at	$^{-}3$	
	correct answer	$^{+}3$	
	Cecily's answer	$^{+}1$	
			missed!

Whatever is going on in Cecily's head is fairly complicated,[8] but you can explain a great deal of it if you assume the following:

1. Cecily was not relying primarily on the numerals, but rather on the picture of the number line.

2. Her basic error was to count the division marks, rather than the number of unit intervals.

[8]The author was assisted in both the observations and in their analysis by Sharon Dugdale, a PLATO lesson designer.



[This by itself explains the errors in problems 1, 7, and 9, and her (wrong verbal remark in problem 10.]

3. However, she did have a correct procedure available in her repertoire; the choice of the correct or incorrect procedures was somewhat random, but was influenced by the cognitive difficulty of that particular task: the greater the difficulty, the more likely a wrong choice (cf. Davis, 1971-2 B). This may explain why Cecily made a correct choice on problem 2 ($\bar{}10$ and $\bar{}13$ being easy for her to deal with?), on problem 5 (again, $\bar{}10$ and $\bar{}13$), and on problem 11 ($\bar{}4$ and $\bar{}6$ being easy for her?).

4. It may have been the case that getting the n^{th} problem correct increased the likelihood of selecting the correct sub-procedure for problem n + 1, especially if the (n + 1)st problem was cognitively similar to the n^{th} problem. This might explain the correct answer on problem 3 (where the numbers were $\bar{}13$ and $\bar{}8$).

There is something interesting to be studied here. For the immediate

task of improving the effectiveness of this lesson, however, there are many possible ways to proceed. Here is one: since we do believe in the phenomenon of regression under conditions of cognitive overload, perhaps the lesson should at first use only positive integers, with the victim on the right, so that the correct answer is also positive, and one has only the pattern of straightforward addition (adding the helicopter's move to its original position):

victim at	12
helicopter at	8
correct answer	4

In order to make sure that students are (sooner-or-later) using the numerals instead of the picture, after a while, suppress the written scale on the picture. (Following David Page's suggestion, you could also go to larger numbers, thus compelling a use of the subtraction algorithm, as in:

victim at	1492
helicopter at	856
correct move	?

but this might be counterproductive, since it may represent a premature appearance of a further complicating factor.)

The continuation of the lesson in this fashion follows fairly obviously.

IV. Summary

The fear is often expressed that "being scientific," as a slogan, is

nowdays frequently leading to oversimplifications of reality, and thus to poor educational practice. Our experience, unfortunately, tends to confirm this.

On the opposite side, when we try to approach the task of lesson designing in a systematic, theory-based fashion, we encounter two major obstacles:

i) The situation-specific aspects of lessons seem to dominate the generalizable aspects; and ii) The scale of feedback is far different from the usual "scientific" scale: instead of studying a thousand students for a year (although this is important), we get our most valuable design ideas from studying a few students for a few minutes, and then implementing some changes.

We are left with the belief that, in 1976, too much attention is focusing on "being scientific," and far too little attention is focusing on design. Design in education has much in common with design in women's dresses, or in furniture, or in architecture. The effective study of design probably needs to build on case studies more than on generalizations.

Careful naturalistic observation has received far less attention than it deserves. Before we get too involved in phenomena, methodology, or theories, we need to take a good look at what's going on. The methods of good journalists can help, at this stage, more than the subtler methods of statisticians.

It might help us to move out of this dilemma if we dropped "science" as a slogan-word, and instead tried to use more precise and emotionally-neutral descriptors, such as these:

Does the observation method depend upon a rather fully-structured,

explicit a priori procedure, or does it depend upon observer choice in selecting observations?

Is the interpretation of observations related to a theory, or not? If so, to what theory?

Are descriptors applied to observed gestalts, or to sharply-defined single variables?

The slogan of "being scientific" does NOT, at present, seem genuinely helpful. We can, and must do better.

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